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# REVIEW OF THE NITROGENOUS CONSTITUENTS OF THE POTATO[1]

## NUTRITIVE VALUE OF THE ESSENTIAL AMINO ACIDS

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The potato has been a primary dietary constituent of modern civilizations. There may be some question about the relative role of the potato in the diet of certain medieval populations, such as the early South American Indians, but the importance of this foodstuff for centuries to inhabitants of Europe and the British Isles is a matter of record. Today the potato is still the most important vegetable for a large portion of the world's population. In spite of this historical background, the complete nutritional value of the potato has not been fully appreciated. The fact that starch constitutes two-thirds to three-fourths of its dry weight has directed our attention away from its important vitamins, minerals, and amino acids. Within the past two decades, it has been recognized that the potato is an important supplier of vitamin C. It was reported 25 years ago, however, that human adults were kept in nitrogen balance and in good health for as long as 5 months when fed diets consisting solely of potatoes and a small amount of fat (9, 12). This indicates that, with the possible exception of fat and fat-soluble indispensable nutrients, potatoes contain practically all essential dietary factors.

It is the purpose of this paper to review the nitrogenous constituents of potatoes with particular emphasis on the nutritional value of the eight amino acids indispensable to man.

Table 1 shows the range of nitrogen contents of several varieties of potatoes, reported by Neuberger and Sanger in 1942 (10).

Total N ranged from 0.24 to O.36 per cent of fresh weight. Our comparable analyses ranged from 0.20 to 0.42 per cent. On a moisture-free basis, the N values are 1.16-1.95 per cent. The percentage of N compounds can be estimated on a dry-weight basis by multiplying the 1.16 and 1.95 extremes by 6.25. In this case, the N-containing compounds comprise 7.2 to 12.2 per cent of the dry matter—or, let us say, 10 per cent for a general average. There is a rather wide variation in all these percentage N values.

### Trace Compounds

In addition to the amino acids, amides, and proteins, numerous constituents, present in only trace quantities, should be included in any consideration of the nitrogenous materials. These trace compounds, mentioned by Burton (1), include the enzymes, vitamins, the alkaloid solanine, and other basic nitrogen compounds.

[1]Accepted for publication May 29, 1953.

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| | | |
|---|---|---|
| Total N, as per cent of fresh weight | | 0.24— 0.36 |
| " N, " " " " dry " | | 1.16— 1.95 |
| Protein N, | as per cent of total N | 37.0 —63.7 |
| Asparagine N, | " " " " " N | 11.8 —27.0 |
| Glutamine N, | " " " " " N | 7.6 —19.7 |
| *Alpha*-Amino-acid N, | " " " " " N | 6.4 —12.8 |
| Basic N, | " " " " " N | 20.4 —27.7 |

The following enzyme systems have been reported: Tyrosinase, amylase, catalase, polyphenoloxidase, aldehydrase, phosphatase, phosphorylase, glyoxalase peroxidase, sisto-amylase, dehydrogenase, and zymohexase.

The amylase and/or phosphorylase systems are responsible for the formation of sugars during cold storage. The tyrosinase system catalyzes one form of enzymic discoloration in peeled potatoes. Further understanding of these complex systems could contribute materially to the solution of practical problems encountered in the handling, storing, and processing of potatoes.

The following nitrogen-containing vitamins have been found in the potato: Thiamin, ($B_1$); riboflavin, ($B_2$); the anti-pellagra factors, nicotinamide and trigonelline; pyridoxine ($B_6$); and choline. One would probably assume the presence rather than the absence of other N-containing vitamins, such as pantothenic acid, biotin, folic acid, and p-aminobenzoic acid.

Other trace compounds include adenine, cadaverine, xanthine, hypoxanthine, solanine, and guanine. Of these, the alkaloid solanine has received most attention. This alkaloid is present primarily in or near the skin, and unusually high concentrations have been attributed to exposure of the tubers to sunlight in the field. Chemically, solanine is probably an alkaloidal glycoside, since on hydrolysis it yields glucose, galactose, rhamnose, and the alkaloid solanidine. Several chemical formulas have been proposed.

## The Amides

Extensive work on the amide fraction of potatoes has been done by F. C. Steward (15). The principal amides are asparagine and glutamine, and they contain, as shown in table 1, from 11.8-27.0 and 7.6-19.7 per cent of the total nitrogen, respectively. The amide nitrogen of glutamine is more easily hydrolyzable than that of asparagine. When plants receive nutrients rich in ammonia, they produce large quantities of one of these amides.

Vickery, Pucher, and Clark (19) have suggested that in any green plant only one of the amides detoxifies ammonia and that the function of the second amide is by no means clear.

The easily hydrolyzable amides are regarded as reactive intermediates between amino acids and more stable amides on the one hand and proteins on the other. Glutamine and glutamic acid in particular appear to be important in transamination reactions catalyzed by enzyme systems.

Additional nutritional significance is provided by the observation of Rose, Oesterling, and Womack (14) that the growth of weanling rats was definitely stimulated by the addition of glutamic acid to a diet that was adequate with respect to the 10 essential amino acids. In short, the nutritionally important amides, asparagine and glutamine, are present in relatively large amounts in potato sap.

## The Amino Acids

When Dent, Stepka, and Steward (4) in 1947 analyzed a solution containing the soluble, non-protein nitrogen fraction of the potato, by the paper chromatography technique, they hit the proverbial jackpot. They reported "By this means, positive and, we believe, unequivocal identification has been achieved of 21 amino acids as normal constituents of the alcohol-soluble nitrogen of potato tuber tissue and three more still await identification." Positive identification was reported for cystine, aspartic and glutamic acids, serine, glycine, asparagine, threonine, alanine, glutamine, *alpha*-amino-n-butyric acid, histidine, arginine, lysine, methionine sulfoxide, proline, valine, methionine, isoleucine, phenylalanine, tryptophane, and tyrosine. The amino acids subject to investigation and confirmation, or present in minimal amounts were *beta*-alinine and two distinct amino acids near the position occupied by proline on the paper chromatogram. The two last-mentioned substances were previously observed by Dent in animal material and therefore seem to be of general distribution in nature. There was a preponderance of isoleucine over leucine (the latter was not definitely found), cystine and methionine were not so conspicuous as expected, hydroxyproline was not positively detected, and *alpha*-amino-n-butyric acid was present only in traces. It is believed that the last-named acid is a break-down product of an amino acid, rather than an intermediate of protein synthesis, since its presence was previously claimed in blood and urine (3).

In 1949, Steward, Thompson and Dent (16) reported the detection of *gamma*-amino-butyric acid as a component of the free amino acids of the potato. This acid accounted for 5 per cent of the alcohol soluble N and 3.7 per cent of the total N of the Katahdin potatoes examined. This acid does not occur in the protein hydrolyzate but is used by potato cells in protein synthesis.

Zacharius, Thompson, and Steward (21) recently reported the occurrence in fresh green beans, and probable occurrence in potatoes and mushrooms, of *levo*-pipecolic acid. This is piperidine 2-carboxylic acid — or the 6-membered ring homologue of proline.

## The Proteins

Before the turn of the century, Osborne and Campbell (11) isolated a globulin, which they named tuberin, in expressed potato juice. Another protein fraction was isolated from the residual pulp by extraction with sodium chloride solution. Since these proteins had similar elementary compositions, similar precipitation limits with $(NH_4)_2SO_4$, and seemingly comparable heat coagulation behavior, these workers considered them to be identical. Fifty years later (1946) Groot and coworkers (6) in Amsterdam found that Osborne's tuberin was actually a mixture of two proteins, which could be separated by electrophoresis, by precipitation at different pH values, and by fractional precipitation with $(NH_4)_2SO_4$. For the protein precipitated at the lower pH, they sugggested the name "tuberinin," and retained the name "tuberin" for the other protein. The ratio of tuberin to tuberinin was 71/29. However, Jırgensons (8) suggests that owing to the labile nature of proteins in potato juice, several different proteins can be separated, depending on the methods employed. Furthermore, it should be borne in mind that the number of proteins will be dependent on the system of classification. For example, each enzyme system involves a separate and distinct protein.

Several years ago Chick and Slack (2) reported the isolation of *alpha*- and *beta*-globulin from potato press juice. In freshly dug potatoes, the ratio of *alpha* and *beta* was 1 to 2; in a sample of stored potatoes it was 2 to 1.

When we consider that the potato is in reality a well-stocked reservoir of free amino acids, enzyme systems, labile proteins, carbohydrates, and metabolically important amides, we can better appreciate its behavior. Possibilities for numerous and varied reactions are provided. Unfortunately, many of these reactions are of an undesirable nature and lead to discoloration and deterioration in handling, storing, and processing. When we accumulate more of the basic knowledge of all the constituents, we shall be in a position to control these undesirable changes.

## Nutritional Studies

The nutritional value of the amino acids and proteins is of particular interest to the potato industry. As a result of several recently completed studies, we are now in a better position to appreciate and interpret nutritional data. In the words of Thompson (18): "When you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

Our present ability to express numerically the nutritional value of the amino acids and proteins of the potato is derived from the classic works of Chick and Slack (2) in England, Groot (5) in Holland, and Steward (17) and Rose (13) in this country.

The fact that the nitrogen of the potato, weight for weight, is as efficient as that of wheat and closely approximates casein, for maintenance of nitrogenous equilibrium in adult man or animals, has been abundantly demonstrated. Three years ago Chick and Slack wrote about this as follows: "The reason why this should be so, seeing that 50 per cent or more of the potato nitrogen is non-protein in nature, puzzled Rubner 70 years ago. The puzzle remains unsolved, in spite of the advances in knowledge of proteins and nutrition which have been achieved since the period when Rubner was confronted with it."

Chick and Slack have made comparative studies of the nutritive value of the fractions shown in table 2 with that of the whole potato on an equivalent nitrogen basis. What they actually compared was the protein fraction, the non-protein nitrogen fraction, a mixture of these two in the ratio of their occurrence in the potato, and the whole potato. The nutritive values were judged by the capacity to support the growth of weanling rats. They found that on the basis of nitrogen content, the nutritive value of their tuberin was not superior to that of the mixture of protein and non-protein nitrogenous material in the whole potato. The non-protein nitrogen in the press-juice, after removal of the tuberin, was unable to support growth, but when combined with tuberin in the proportions in

TABLE 2.—*Amino-acid-content of potato sap.*

(g./16 g. N)

| | (1) Tuberin Fraction | (2) N. P. N. Fraction | (3) 53 Parts (1) + 47 " (2) * |
|---|---|---|---|
| Phenylalanine | 6.6 | 4.1 | 5.4 |
| Leucines | 17.5 | 4.3 | 11.3 |
| Valine | 6.1 | 3.3 | 4.8 |
| Tryptophan | 1.6 | — | 0.8 |
| Threonine | 5.9 | 1.1 | 3.7 |
| Arginine | 6.0 | 2.6 | 4.4 |
| Histidine | 2.2 | 1.1 | 1.7 |
| Lysine | 7.7 | 1.9 | 5.0 |
| Cystine | 2.1 | 1.2 | 1.6 |
| Methionine | 2.3 | 0.8 | 1.6 |

*The proportions in which the protein and N.P.N. were present in the sample of potatoes used. (Ref. 2).

which non-protein and protein nitrogen exist in the whole potato, the nutritive effect between the tuberin and protein-free fraction of the press although still inferior to that of the nitrogenous mixture *in situ* in the intact tuber. This result shows a complimentary nutritive action between the protein and the non-protein nitrogen in the potato. The supplementary nutritive effect between the tuberin and protein-free fraction of the press juice could not be explained on the basis of their amino acid contents. The tuberin fraction was richer in all essential amino acids than was the non-protein nitrogen fraction as shown in table 2.

What can be said of the quality of these nitrogenous constituents with regard to human nutritional requirements? Because of recently completed nutritional investigations by Rose and collaborators (13), we are now in a position to calculate the value of these nitrogen components. These tests were made on a comparatively large number of healthy male graduate students during the last 10 years. It was shown qualitatively that man requires only the eight amino acids shown in column 1 of table 3, when sufficient nitrogen is available in the diet for synthesis of the non-essential amino acids. Histidine, which is indispensable for the rat, and arginine, which is necessary for its minimum growth, are not required for the maintenance of nitrogen equilibrium in normal human adults.

The smallest amount of each of the eight essential amino acids that would maintain human nitrogen equilibrium was also determined. The minimum daily requirement of each is shown in column 2 of table 3. In other words, adults require the indicated amount of the respective amino acids for the maintenance of health. A safety factor is provided in that the recommended daily intake, shown in column 3, is twice the minimum requirement.

A word of caution is also supplied by Rose: "Discussion has been limited to the indispensable amino acids. This emphasis should not lead to the impression that the so-called non-essentials possess little significance.

TABLE 3.—*Minimum and recommended intakes of the essential amino acids for normal man.*

(When the diet furnishes sufficient nitrogen for the synthesis of the non-essentials.)

| Amino Acid | Minimum Daily Requirements, Grams | Recommended Daily Intake, Grams | Number of Subjects Tested |
|---|---|---|---|
| L—Tryptophan | 0.25 | 0.5 | 37** |
| L—Phenylalanine | 1.10 | 2.2 | 28 |
| L—Lysine | 0.80 | 1.6 | 33 |
| L—Threonine | 0.50 | 1.0 | 24 |
| L—Valine | 0.80 | 1.6 | 29 |
| L—Methionine | 1.10 | 2.2 | 19 |
| L—Leucine | 1.10 | 2.2 | 14 |
| L—Isoleucine | 0.70 | 1.4 | 14 |

**Thirty three were kept in balance on 0.3 gram or less.

As a matter of fact, all exist as tissue components, even though they may be excluded from the food."

In view of the results of Chick and Slack and of Rose, we can now appreciate the nutritional value of the free amino acids in potato juice. The quantitative data on these essential amino acids permits calculations that should be of interest to all. For example, how much of the minimum daily requirements of the eight essential amino acids is supplied by potatoes? On the basis of the annual *per capita* consumption in the U. S. of 104 pounds, an average of 130 grams is eaten daily. This ration contains about 0.4 gram of nitrogen and on the basis of Chick and Slack's analytical studies, which are largely confirmed by Groot (5), Steward (17), and Hirsch (7), contains the calculated amounts of amino acids shown in column 2 of table 4.

TABLE 4.—*Essential amino acids supplied by average daily ration of potatoes.*

| Amino Acid | Amount in 130 Gms. Whole Potatoes, Grams | Minimum Daily Requirements, Grams | Per cent Minimum Daily Requirement |
|---|---|---|---|
| L—Tryptophan | 0.02 | 0.25 | 8 |
| L—Phenylalanine | 0.135 | 1.10 | 12 |
| L—Lysine | 0.125 | 0.80 | 16 |
| L—Threonine | 0.093 | 0.50 | 18 |
| L—Valine | 0.120 | 0.80 | 15 |
| L—Methionine | 0.05 | 1.10 | 4-5 |
| L—Leucine | 0.115 | 1.10 | 14 |
| L—Isoleucine | 0.093 | 0.70 | 13 |

Dividing each value by the minimum daily requirement shown in column 3 gives column 4, the approximate percentages of our minimum daily requirements of essential amino acid supplied by potatoes on a *per capita* consumption basis. You will note that these figures are 8 per cent for tryptophane, 12 for phenylalanine, 16 for lysine, 18 for threonine, 15 for valine, 4-5 for methionine, 14 for leucine, and 13 for isoleucine. It should be borne in mind that this calculation is only approximate and that twice the minimum requirement is recommended for daily consumption.

In six European countries, the annual *per capita* consumption of potatoes during the period 1934-1938 (as reported by Yates (20)) was

| | Pounds |
|---|---|
| Switzerland | 198 |
| Great Britain | 210 |
| Denmark | 246 |
| Germany | 398 |
| France | 400 |
| Belgium | 440 |

These data indicate that in Belgium, France, and Germany potatoes supplied approximately the following percentages of the minimum daily requirements of essential amino acids.

| | Per cent |
|---|---|
| Tryptophane | 32 |
| Phenylalanine | 48 |
| Lysine | 64 |
| Threonine | 72 |
| Valine | 60 |
| Methionine | 16-20 |
| Leucine | 56 |
| Isoleucine | 52 |

A further check on the validity of this type of calculation is afforded by the data of Kon and Klein (9), which showed that human adults were maintained in nitrogen balance and in good health for as long as 5 months on diets that included potatoes as the only source of nitrogen. For an adult man, the daily consumption of potatoes was slightly less than 4 pounds, which furnished about 5.7 grams of nitrogen. This quantity of nitrogen is 14.2 times the value employed in calculating the percentages in the last column of table 4. Accordingly, multiplication of the latter percentages by 14.2 should yield percentages equal to or greater than 100 per cent. This was found to be true except in the case of methionine. Varietal differences in amino acid composition (17) or difficulties in the methionine assay might possibly account for this discrepancy.

These calculations are based on analyses of raw potatoes. Comparable analytical data on stored and cooked potatoes would be more pertinent. Nevertheless, the calculations demonstrate emphatically that in addition to carbohydrates potatoes contain appreciable amounts of the amino acids essential to man.

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